

Funds Requested: \$160,012 (for 7/01/2003-6/30/2005)

Project Title: **CONCRETE DIFFUSION COEFFICIENTS AND EXISTING CHLORIDE EXPOSURE IN NORTH CAROLINA**

Purpose of Proposal: During this project, an investigation will be performed to determine a correlation between the RCPT results and the diffusion coefficients of the same concrete samples. This correlation will be performed on 15 concrete mix designs specified by the NCDOT engineers. The results of this work will support a mathematical model to be used in predicting the service life of bridges across North Carolina. The project will also include the evaluation of core samples taken from 25 reinforced concrete (RC) bridges located in various geographical locations. The data generated in this phase will provide comprehensive chloride profiles and chloride loading data for regions of North Carolina and for typical bridge structural components. Among these 25 bridges, special attention will be given to the US264 structure over the Croatan Sound (Manteo Bypass), by performing a thorough analysis of the RCPT values obtained throughout the structure.

Prepared by: Janos Gergely, Ph.D., P.E.
Assistant Professor, Structures and Materials
UNC Charlotte, Civil Engineering Department
9201 University City Blvd., Charlotte, NC 28223
Tel: (704) 687-4166, Fax: (704) 687-6953
Email: jgergely@uncc.edu

Subdivision: NC DOT Structures/Materials

Principal Investigator: Janos Gergely, Ph.D., P.E.

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TABLE OF CONTENT

INTRODUCTION	3
BACKGROUND	3
PROBLEM DEFINITION	3
RESEARCH OBJECTIVES	4
LITERATURE REVIEW	4
RESEARCH METHODOLOGY AND ITEMIZED TASKS	5
SIGNIFICANCE OF PROPOSED WORK	6
IMPLEMENTATION AND TECHNOLOGY TRANSFER	7
NCDOT RESOURCES	7
PROPOSED WORK SCHEDULE	8
RESEARCHER QUALIFICATION	8
REFERENCES	8
BIOGRAPHICAL DATA	10
BUDGET JUSTIFICATION	11
ITEMIZED BUDGET	12

INTRODUCTION

Lately, a new design approach is being used to design and specify materials for building structures and bridges. This approach, the performance based design, however, considers mostly strength characteristics, and often overlooks the durability performance of these structures. This alone will not be a concern for a large number of structures, but it will shorten the life expectancy of bridges for example, if located in an aggressive environment. For reinforced concrete (RC) bridges the corrosion problems start to affect the performance of the structure when high chloride concentrations reach the reinforcing steel, causing severe oxidation, and ultimately the total loss of reinforcement. Therefore, it is important to determine the location and the amount of extreme chloride “loading” (in the form of deicing materials or sea water), and use this information to design for a more realistic service life for bridges across the State.

BACKGROUND

As stated by Mr. Rodger Rochelle, NCDOT State Research Engineer, “the design for durability in concrete structures is paramount to extend bridge service lives and reduce the bridge maintenance backlog”. In the past, corrosion protection measures utilized across North Carolina involved the selection of corrosion-inhibiting materials based on simplified geographical and historical chloride loadings. The lack of precise information on actual chloride loadings, however, means current corrosion protection measures may not be satisfactory. More recently, a mathematical model to predict bridge service life is being used in North Carolina, particularly on coastal bridges. This model is based on predicting corrosion. With additional research and data, this model will provide a procedure by which corrosion policies can be refined for bridges state-wide.

The results of this project will assist NCDOT engineers in designing and maintaining bridges to last 75-100 years. As a result, potential life-cycle cost savings are significant. Furthermore, with the above-mentioned results in hand, future research could focus on existing bridges. By taking samples of the most vulnerable components from bridges located in geographic regions with high chloride loading, it would be possible to estimate the remaining life of those bridges.

PROBLEM DEFINITION

The present research idea was developed by Mr. Rodger Rochelle, State Research Engineer at NCDOT, and it was prompted by the need to estimate the durability performance of bridges across the State. In order to accurately prescribe mix components to prolong concrete service life, diffusion coefficients for typical bridge concrete mixes must be determined. Rapid Chloride Permeability Tests (AASHTO T277, RCPT) have been performed on concrete samples from several North Carolina bridges. The results have lent insight into the relative benefits of various concrete admixtures.

However, the RCPT is not a direct test of concrete permeability and does not explicitly yield a diffusion coefficient for the concrete being tested. Both the concrete's diffusion coefficient (or coefficient of permeability) and the chloride exposure level are required in the mathematical model, based on Fick's Second Law of Diffusion, used to predict service life. By obtaining representative values for these required items from typical bridges across the state, the mathematical model will be used to vastly refine the corrosion protection measures currently employed on bridges statewide.

RESEARCH OBJECTIVES

The scope of work of the present proposal includes two main objectives. First, an investigation will be performed to determine a correlation between the RCPT results and the diffusion coefficients of the same concrete samples. The same procedure will be done on 15 concrete mix designs currently specified by the NCDOT engineers. In order to adequately determine the diffusion coefficient of concrete samples with admixtures, the standard 90-day ponding test will be extended to at least 180 days (6 months).

The second phase of this project will involve core samples taken from 25 RC bridges located in various geographical locations. Furthermore, from each bridge, samples will be taken from several major components, and a chloride profile will be developed for each test specimen. The data generated in this phase will provide comprehensive chloride profiles versus depth in selected samples and a chloride loading data for regions of North Carolina and for typical bridge structural components. Also, among the bridges analyzed in this project, a thorough RCPT analysis will be performed on the Manteo Bypass (US264 structure over the Croatan Sound), using samples collected throughout the bridge.

LITERATURE REVIEW

In order to implement a 100-year service life for North Carolina's coastal structures, an extensive corrosion modeling was done by Rochelle (2001) at the North Carolina Department of Transportation (NCDOT). This approach was then used to design each specific element group in the Manteo Bypass, opened for traffic a few months ago. This methodology allowed the design engineers to specify a concrete mix with different admixtures for the deck, girders, bent caps, etc..., a mix based on the expected chloride exposure levels. It is expected, that the reinforcing steel in each structural member will start to corrode simultaneously after approximately 95 years, and the bridge will then be replaced after a century of service. As part of this proposed project, a thorough RCPT analysis will be performed on this structure, using samples collected throughout the bridge.

A reliability-based assessment of offshore concrete structures was done by Faber et al. (1999). A probabilistic approach was presented to assess chloride-induced corrosion of reinforcing steel. This approach enhances the inspection and maintenance planning for the structures investigated in the North Sea. To solve the diffusion equation the finite element method was used. Based on the statistical characteristics of the chloride surface

concentration, the time can be approximated until corrosion initiation, visible corrosion, and finally concrete cover spalling.

A laboratory assessment was performed by Snooddy (1995) on the permeability and diffusion characteristics of typical types of Florida concrete. Specimen permeability was measured using a device developed for the project, and the diffusion coefficient was determined based on a newly developed system. It was determined that the w/c ratio, the amount of sand and stone, as well as the presence of fly ash affected the permeability of the concrete and the diffusion coefficient.

In another research project in this field, Luping (1996) has been concentrating on the basic theories involving chloride transport in concrete. Luping also developed a measurement method and a prediction model for concrete structural members submerged in sea water.

RESEARCH METHODOLOGY AND ITEMIZED TASKS

1. Selection of mix designs: Select 15 typical mix designs currently used in North Carolina. These mix designs will include plain concrete mixes, as well as different admixtures, such as calcium nitrite, fly ash and microsilica. If it is determined that a mix design requires a specific aggregate type commonly used for one region, sufficient amount of this material will be obtained to prepare the samples.
2. Sample preparation and curing: Since both the ponding test and the RCPT will be performed on the same mix design, three slabs and three cylinders will be prepared for each mix design (i.e. a total of 45 slabs and 45 cylinders will be prepared). The existing curing room at the structures/materials lab will be used to accommodate the curing requirements specified in the AASHTO T160-97 standard specification. To obtain an identical curing for each test group all the slabs and cylinders will undergo the same curing process.
3. Ponding test: In order to determine the diffusion coefficient of each concrete mix design, three slabs will be tested from each mix using the long-term ponding test AASHTO T259-80. Mr. Rochelle indicated that some of the mix designs will contain a variety of admixtures, which will not allow an easy chloride penetration within the 90 day ponding period. To obtain meaningful results, the ponding period for these samples will be extended up to six months or more, a time period to be determined by the NCDOT and UNCC personnel.
4. Rapid chloride permeability test (RCPT): After subjecting each cylinder to the same curing time as the slabs within the same mix design, 2 in. thick slices will be cut from each sample using a concrete saw, and a rapid chloride permeability test will be performed according to AASHTO T277/ASTM C1202-97. During an earlier meeting, NCDOT personnel at the Materials Unit advised the UNCC researchers that an RCPT apparatus will be loaned to Charlotte for the duration of the project.

5. Data analysis and correlation of results: The results from both tests will be analyzed using currently available mathematical procedures. Since the ponding test will be running through a longer period of time, and will end at different time for each mix design, this analysis procedure will be ongoing. A correlation will be made between the two test results (i.e. AASHTO T259 as compared to AASHTO 277), and a research report prepared on the first phase of this research project.
6. Selection of bridges: NCDOT personnel in collaboration with the UNCC group will select 25 bridges across the State of North Carolina, with emphasis on expected high chloride concentration. The selection will be made based on several criteria, such as geographic location, estimated chloride loading, RC component type (i.e. prestressed vs. cast-in-place components), etc... The selected bridges should provide a net of information on the vulnerability of bridges in each region. Mr. Rochelle in his letter to the researcher from UNCC indicated, that a full RCPT analysis will be required on the US264 structure over the Croatan Sound (Manteo Bypass).
7. Bridge core sampling: From the selected bridges the NCDOT field personnel will core samples from several different components of each bridge. The number and location of each core is to be determined later, but in order to complete the project within the time frame allowed, the total number of samples should be reasonable. Members of the UNCC group will be present at each sampling, and provide input as requested. Each sample will be marked and transported to the materials laboratory at UNCC for further testing.
8. Determination of a chloride profile: For each sample a chloride concentration will be obtained at a predetermined depth. This will be done following the procedures outlined in AASHTO T260-97. Following these tests a chloride profile will be determined, and it will be possible to build a chloride loading data from various bridges and structural components across the State.
9. Recommendations on chloride mitigation policy: With the chloride loading data determined in Task 8, recommendations will be provided on the efficacy of NCDOT's current corrosion mitigation policy in light of the statewide chloride exposure. An additional report will be produced on this second phase of the research project proposed.

SIGNIFICANCE OF PROPOSED WORK

As described by Mr. Rochelle: "The efforts here aim to reduce the maintenance backlog by allowing the DOT Engineers to design bridges that can last 75-100 years with significantly reduced maintenance. The potential life cycle cost savings are dramatic. Specifically, in some instances, life cycle costs will be greatly reduced by protecting all components of a bridge in an equitable manner, thereby eliminating the bridge's weak link in regards to durability."

Furthermore, with the above-mentioned results in hand, a future research project could focus on existing structures. By taking samples of the most vulnerable components from bridges within the highest chloride loading zone, it could be possible to estimate the remaining life of that structure. This could be done by using the chloride loading information determined in this project, and by combining this with RCPT values on cores taken from non-exposed members. These RCPT values on the other hand should correlate to diffusion coefficients, and by using the same mathematical model as the one used in the present project, the time to chloride saturation at reinforcement level can be approximated. With this information, bridge replacement/repair can be scheduled for a longer time ahead, thus allowing NCDOT to schedule the resources and traffic control well in advance.

IMPLEMENTATION AND TECHNOLOGY TRANSFER

The products of the proposed research project will be the correlation between the RCPT and ponding test results, as well as a chloride loading profile for structures throughout the State of North Carolina. The two project reports will also include recommendations that will be used by NCDOT personnel as the basis for a comprehensive corrosion policy. Based on the results from the tests, a mathematical model will be used for each region of the state to refine the corrosion mitigation measures applied to that region's structures.

NCDOT RESOURCES

The resources requested from NCDOT to perform the proposed project tasks include:

- Information on the 15 typical mix designs, including any special aggregate or admixture needed. Also, information on previously performed RCPT and ponding tests on any of the selected mix designs.
- RCPT apparatus for the duration of the project, including spare accessories and training to UNCC personnel.
- Sample coring from 25 bridges across the State of North Carolina taken from different components of each bridge.

PROPOSED WORK SCHEDULE

The following table provides information on the anticipated time schedule for the project:

TASKS		24 Months											
1.	Mix Design Selection	x	x										
2.	Sample Preparation/Curing		x	x	x								
3.	Ponding Tests (AASHTO T259)			x	x	x	x	x	x				
4.	RCPT Tests (AASHTO T277)				x	x	x	x	x				
5.	Data Analysis/ Report 1					x	x	x	x	x			
6.	Selection of Bridges				x	x	x	x					
7.	Bridge Sampling/Coring					x	x	x	x				
8.	Chloride Profile						x	x	x	x	x		
9.	Recommendations/ Report 2										x	x	x

RESEARCHER QUALIFICATION

The PI has performed several concrete bridge research projects involving high-performance materials, and in the near future he will re-propose a durability study on a special reinforcing steel product. He also has extensive experience in material testing and characterization. The PI and his graduate/undergraduate students are supported by fully equipped material and environmental laboratories.

REFERENCES

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- AASHTO T259, “*Resistance of Concrete to Chloride Ion Penetration*,” American Association of State Highway and Transportation Officials, Washington DC, 1981.
- AASHTO T260, “*Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials*,” American Association of State Highway and Transportation Officials, Washington DC, 1999.
- AASHTO T277, “*Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration*,” American Association of State Highway and Transportation Officials, Washington DC, 1998.
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- R. Snooddy, “*Laboratory Assessment of the Permeability and Diffusion Characteristics of Florida Concretes: Phase II. Field Samples and Analyses*,” Environmental Protection Agency, Report, July 1995.
- K. Stanish, R.D. Hooton, and M.D.A. Thomas, “*The Rapid Migration Test – An Alternative to AASHTO T2777*,” HPC Bridge Views, No. 13, Jan/Feb 2001.

Janos Gergely, Ph.D., P.E.

a. Professional Preparation

Polytechnical Institute of Cluj-Napoca, Romania	Civil Eng.	Dipl. Eng.	1990
University of Utah	Civil Eng.	M.Sc.	1996
University of Utah	Civil Eng.	Ph.D.	1998

b. Appointments

1998-present	Assistant Professor, Dept. of Civil Engineering, UNC Charlotte
1995-present	Technical Consultant in seismic retrofit and strengthening projects
1994-1998	Graduate Research and Teaching Assistant at the University of Utah
1992-1994	Project Engineer at a construction company in Germany
1990-1992	Field Engineer (part time) in Romania and Austria

c. Selected Publications

1. J. Gergely, and D.T. Young, “*In-plane and Out-of-plane Behavior of Unreinforced CMU Walls Retrofitted with Composites*,” Journal of Composites for Construction, ASCE, to be submitted in Spring 2003.
2. M. Beigay, D.T. Young, and J. Gergely, “*Composite Wall Anchors*”, Advanced Polymer Composites for Structural Applications in Construction ACIC 2002, Southampton, UK, April 15-17, 2002, proceedings.
3. P.R. Salom, J. Gergely, and D.T. Young, “*Torsional Strengthening of Spandrel Beams with FRP Laminates*,” Journal of Composites for Construction, ASCE, accepted for publication Spring 2003.
4. J. Gergely, D.T. Young, J.L. Hooks, and N. Alchaar, “*Composite Retrofit of Unreinforced CMU Walls*,” Advancing with Composites (PLAST 2000) International Conference, Milan, Italy, May 2000.
5. H. Emmanuel, J. Gergely, and D.T. Young, “*Masonry Composite Bond Behavior*,” University of North Carolina at Charlotte Research Report, September 2000.
6. I. Gergely, C.P. Pantelides, and L.D. Reaveley, “*Shear Strengthening of R/C T-joints Using CFRP Composites*,” Journal of Composites for Construction, ASCE, May 2000.
7. V.A. Volnyy, C.P. Pantelides, J. Gergely, C.L. Hofheins, and L.D. Reaveley, “*Carbon Fiber Composite Connections For Precast Concrete Wall Panels*”, ACI Structural Journal, submitted, July 1999.
8. C.P. Pantelides, I. Gergely, and L.D. Reaveley, “*Retrofit and Test of R/C Bridge Piers With CFRP Composites*,” Journal of Structural Engineering, ASCE, November 1999.
9. I. Gergely, C.P. Pantelides, R.J. Nuismer, and L.D. Reaveley, “*Repair of Bridge Pier with Carbon Fiber Composites*,” Journal of Composites for Construction, ASCE, November 1998.
10. C.P. Pantelides, I. Gergely, L.D. Reaveley, and R.J. Nuismer, “*Rehabilitation of Bridge Cap Beam-Column Joints with Carbon Fiber Jackets*,” Third International Symposium on Non-Metallic (FRP) Reinforcement for Concrete Structures, Sapporo, Japan, October 14-16, 1997.

d. Synergistic Activities

- i. Chair of the ACI 440M Subcommittee formed to develop a *State-of-the-Art Report* and a *Design Guideline* on masonry/FRP applications in collaboration with TMS Existing Masonry Committee
- ii. Developed three courses at UNC Charlotte, including the *Design of Masonry Systems* and the *Composite Materials* courses, as well as advised several ASCE student chapter competition projects
- iii. Developed and presented 8-hour PDH seminars for professionals on the composite applications in infrastructure, and on repair and retrofit of structures
- iv. As a licensed PE in the states of CA and NC, offered consulting services to local engineering firms and to OSHA on structural assessment and strengthening projects
- v. With Dr. Young filed a patent application on composite anchoring systems